Voluntary Remediation Program (VRP) | (307) 777-7752 | http://deq.wyoming.gov/shwd/voluntary-remediation-program/

Vapor Intrusion

In its 2000 session, the Wyoming Legislature created new opportunities, procedures, and standards for voluntary remediation of contaminated sites. These provisions, enacted as Articles 16, 17, and 18 of the Wyoming Environmental Quality Act and implemented by the Wyoming Department of Environmental Quality (DEQ), will govern future environmental cleanups in Wyoming.

This Fact Sheet summarizes DEQ policy on the evaluation and mitigation of vapor intrusion in the Voluntary Remediation Program (VRP) and describes guidance that has been developed by DEQ to assist Volunteers in addressing vapor intrusion when making cleanup decisions about their sites. DEQ expects that Volunteers will refer to this Fact Sheet in conjunction with other applicable Fact Sheets available at http://deq.wyoming.gov/shwd/voluntary-remediation-program/*. During Site Characterization, this Fact Sheet will help Volunteers characterize the potential for vapor intrusion when developing the Vapor Intrusion Site Conceptual Model (VI SCM). This Fact Sheet will also provide guidance on testing, sampling, and evaluation procedures for characterizing vapor intrusion potential, including potential impacts to human health. Finally, this Fact Sheet will provide guidance for addressing vapor intrusion impacts as part of the site remedy.*

1. What is vapor intrusion?

Vapor intrusion is the movement of volatile compounds from the subsurface into the indoor air space of occupied or potentially occupied buildings. Vapor intrusion can occur when a source of volatile compounds, such as contaminated soil (including smear zones above the water table) or groundwater, are present in the ground below or near buildings. Volatile compounds include volatile organic compounds (VOCs), such as benzene or perchloroethylene, and other compounds with a high vapor pressure (VP) or Henry's Law Constant (HLC). When present in non-aqueous phase liquid (NAPL), sorbed to soil, or dissolved in groundwater, volatile compounds can partition into the soil vapor phase and then diffuse laterally and vertically toward the ground surface. The volatile compounds can continue diffusing through cracks or other openings in building foundations and floor slabs and be present in the indoor air. If the building is underpressurized due to thermal (e.g., heat stack), wind, or other mechanisms (such as operation of exhaust fans), soil vapor containing the volatile compounds can be drawn into the building; thus, increasing the rate of vapor intrusion and the resulting impact on indoor air. A simple figure showing an example VI SCM is provided in Attachment A.

The presence of volatile compounds in indoor air does not necessarily imply a complete vapor intrusion pathway that poses risk to human health. Further evaluation of the compound concentrations, the types of receptors, and the exposure duration will be required to determine

whether a human health risk exists at your site. Groundwater, soil vapor, and/or indoor air concentrations may be compared to appropriate screening levels (such as the US EPA vapor intrusion screening levels (VISLs) for either a residential or commercial exposure) to evaluate the potential for vapor intrusion and need for further evaluation or action, as discussed in more detail below.

This Fact Sheet does not apply to occupational settings where the compounds of concern are directly subject to regulation under the Occupational Safety and Health Act (OSHA). Any environmental exposure that may potentially increase risk in a commercial/industrial setting should be considered.

2. Does this Fact Sheet address radon and explosive gas concerns?

No. Radon is a naturally occurring gas that may be present in the soil and enter buildings by the same process as vapor intrusion. However, this Fact Sheet is not intended to address the potential for radon in buildings. If you are concerned about radon, you can find more information on the Internet from reliable websites, such as the US EPA Office of Air and Radiation, or the Wyoming Cancer Program (Radon) under the Wyoming Department of Health.

This Fact Sheet is not intended to address potentially explosive conditions related to natural gas leaks, landfill gas migration, or gasoline spills in or near buildings. If you suspect there is a potential for an explosive gas condition, take immediate actions as necessary.

3. How is vapor intrusion addressed under the VRP?

DEQ considers vapor intrusion to be a potential concern at VRP sites any time there is a source of volatile compounds in the subsurface below or near occupied or potentially occupied buildings, including land that is now vacant but may be developed in the future.

When these conditions exist, or may exist, you should use this Fact Sheet in conjunction with other applicable VRP Fact Sheets, such as Fact Sheet #8 *Site Characterization*, Fact Sheet #11 *Risk Assessment*, Fact Sheet #21 *Remedy Selection*, and Fact Sheet #28 *Data Quality Objectives*.

The list below summarizes steps in the process for addressing potential vapor intrusion at your site. Note that at any time, with DEQ approval, you may elect to proceed directly to preemptive mitigation and remediation (see Question #10).

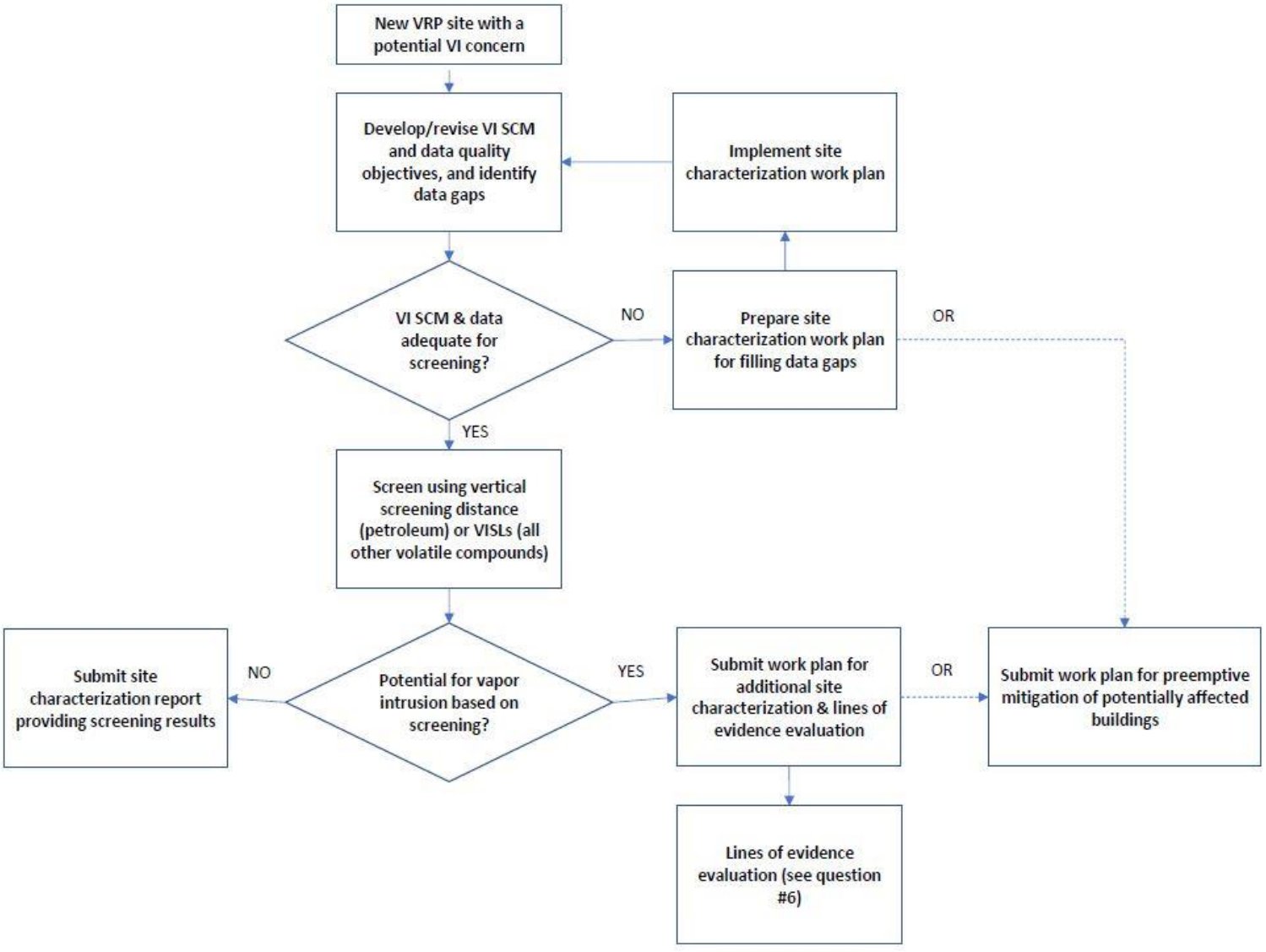
1. Screen the site for the potential for vapor intrusion (see Question #4).

2. If not screened out, further evaluate the potential for vapor intrusion by collecting additional information, if necessary, and considering various lines of evidence (see Questions #5 through #8).

3. If data collected and/or lines of evidence indicate that vapor intrusion is likely occurring (or could occur in the future) and there are building-specific or other exposure factors to consider, evaluate whether an unacceptable risk for exposure to contaminants in indoor air is or could be present (see Question #9).

4. Evaluate long-term remedies by following the VRP process and using Fact Sheet #21 *Remedy Selection*, including the need for interim measures such as engineering controls (see Question #10).

The figure below shows a simplified approach for evaluating vapor intrusion at a new VRP site, not including risk assessment or remedy evaluation.



4. How do I screen for potential vapor intrusion concerns?

First, you should determine whether any compounds that might be present in the subsurface due to releases at your site are sufficiently volatile and toxic to be a vapor intrusion concern. You may do this by collecting groundwater and/or soil gas data during site characterization (see Fact Sheet #8 - *Site Characterization*) and comparing the compound concentrations to the current US EPA VISLs available by searching the US EPA website for the current VISL calculator location. The VISL list indicates whether a chemical meets the definition for volatility (HLC > 1E-5 or VP > 1 mm Hg), and whether inhalation toxicity data for the chemical are available. If these two criteria are met, the potential for a vapor intrusion concern exists, depending on the indoor air concentration and type of exposure (e.g., residential or commercial). If these two criteria are not met or you have any questions about the potential for any specific compounds posing a vapor intrusion risk, consult with your DEQ project manager.

If any such compounds are present, or potentially present in the subsurface at the site, and occupied buildings are located over or near the area of contamination, or may be in the future, you should screen the site for the potential for vapor intrusion as follows:

1. Develop a VI SCM pursuant to Fact Sheet #8 *Site Characterization* that describes the nature of any potential source(s) of volatile compounds in the subsurface, including:

    a. The nature of source material (e.g., NAPL, smear zone, contaminated soil, and/or contaminated groundwater),

    b. The areal extent and depth of the source material,

    c. The concentrations of volatile compounds that are present in groundwater, soil, soil gas, and potentially NAPL (if present),

    d. The potential for the source to migrate in the future (e.g., NAPL or groundwater),

    e. The nature and properties of the vadose zone materials through which soil vapors may migrate,

    f. The locations of any existing or potential future buildings near the area of contamination,

    g. Indoor air concentrations (if available/applicable),

    h. The current or potential use of the buildings (including types of use and occupants) if known,

    i. The locations of any open conduits (such as sewers) that might allow vapors to move more rapidly from the source area to the building, and

j. Any other information that appears relevant to the vapor intrusion pathway at the site.

The VI SCM is ideally presented as a map and cross-section showing the information above in a way that is easily communicated to others, along with summary tables of any data. The VI SCM is not intended to be a comprehensive document at this stage of the screening process, but should be sufficiently complete to communicate known conditions, including any data gaps that limit the understanding of the vapor intrusion pathway at the site.

2. If sufficient information is available in the VI SCM to understand the nature and extent of volatile chemical contamination in subsurface media of concern, then groundwater, sub-slab soil gas, near source soil gas, and/or indoor air concentrations should be compared to the VISLs for these media, as applicable. The type of data required for screening (i.e., groundwater, soil gas concentrations) depends on the nature of the source, as discussed below. If concentrations at the site are below VISLs for applicable media, the vapor intrusion pathway may be screened out at this stage with the following limitations:

    a. DEQ must be satisfied that the VI SCM is sufficiently complete to characterize the vapor intrusion pathway.

    b. If the only source of volatile compounds below a building is dissolved phase concentrations in groundwater, then groundwater samples collected from adequately located wells that are screened across the water table and extending no more than 10 feet below the water table at the time of sampling may be used for screening purposes.

    c. If the source of volatile compounds is from NAPL, smear zone, contaminated soil above the water table, and/or other vadose zone sources, then near source soil gas samples (at depths close to the contamination) or sub-slab soil gas samples are required for screening purposes.

    d. If indoor air data are available, they should be compared to the 1E-6/HQ=1 target indoor air concentrations in the VISL calculator; however, groundwater and/or soil gas data must also be used for screening purposes, as discussed above.

    e. Data must be of sufficient density and quality (see Fact Sheet #28 *Data Quality Objectives*) to represent concentrations over space and time, or the values used for screening must be sufficiently conservative to address this uncertainty.

    f. If any of the above conditions are not met, as applicable, then data gaps may exist and will need to be filled following applicable VRP Fact Sheet procedures before VISLs can be used for screening purposes.

3. If the VI SCM indicates that only petroleum compounds are present in the subsurface, you may also use the vertical separation distance (VSD) screening approaches outlined in *Petroleum Vapor Intrusion* (ITRC, 2014) and *Technical Guide for Addressing Petroleum Vapor Intrusion at Leaking Underground Storage Tank Sites* (US EPA, 2015). If no conditions excluding the use of these approaches exist, then the potential for petroleum vapor intrusion may be screened out if the building is a sufficient distance above the source of petroleum vapors, as described in the ITRC (2014) and US EPA (2015) guidance documents. You should consult with your DEQ project manager before applying the VSD method, and DEQ must be satisfied that the method is properly applied, and that conditions 2(a) and 2(e), above, are met.

4. You should prepare and submit to DEQ for review and approval a concise report documenting the VI SCM; the data relied upon, including a discussion of data quality and uncertainty; the screening process used; the screening results; and your conclusions and recommendations. DEQ will determine whether existing data are sufficient to define the VI SCM and for screening purposes; if not, DEQ will require the submittal of a work plan to fill identified data gaps (see also Fact Sheet #29 *Sampling and Analysis Plans*) before the screening step can be completed. If the VI SCM indicates that the vapor intrusion pathway is complete, it should be noted in the comprehensive SCM for the site.

5. If the results of screening indicate that a potential for vapor intrusion concern cannot be screened out, then you should proceed with the evaluation process described below. Alternatively, you may consider going directly to an evaluation of long-term remedies, and if appropriate, interim mitigation measures to address the potential for exposure to volatile compounds in indoor air. In either case, you are encouraged to first discuss options with your DEQ project manager.

5. How do I evaluate vapor intrusion if not screened out?

The VISLs are deliberately conservative, to minimize the potential for a false negative decision (i.e., screening out the potential for vapor intrusion when it is occurring or could occur in the future). In other words, if groundwater concentrations for dissolved phase plume sources, or soil gas concentrations for NAPL, smear zone, contaminated soil above the water table, and/or other vadose zone sources are below the VISLs, then the potential for vapor intrusion is likely very small and the site can usually be "screened out" with respect to vapor intrusion concerns. On the other hand, if applicable subsurface concentrations are above the VISLs, vapor intrusion may or may not be occurring, depending on the concentrations and site conditions. Further evaluation is needed to determine the potential for vapor intrusion at sites where concentrations exceed the VISLs.

Similarly, the VSDs (per ITRC, 2015 and US EPA, 2014 guidance) for petroleum vapor intrusion sites are also conservative. If the measured vertical separation distance between the building and the source of the petroleum vapors is greater than the applicable VSD, then the potential for vapor intrusion is likely very small due to aerobic biodegradation of the petroleum VOCs, and the site can usually be screened out. If the measured vertical separation distance is smaller than the

applicable VSD, the petroleum VOCs may or may not biodegrade to health protective levels (i.e., below VISLs) before reaching the building, depending on the concentration levels and site conditions. Again, further evaluation is needed to determine whether petroleum vapor intrusion is occurring at these sites.

Multiple Lines of Evidence

Because of the complexity of the vapor intrusion pathway, including the potential for temporal and spatial variability and the potential for other (i.e., "background") sources of volatile compounds to also cause indoor air contamination, DEQ prefers that an evaluation of "multiple lines of evidence" is used to determine whether vapor intrusion is a concern at any site that cannot readily be screened out. This is particularly true if background sources are present and/or the potential indoor air concentrations are close to screening levels or are variable over time. On the other hand, if subsurface concentrations are well above VISLs and the potential for vapor intrusion is considered to be high at the screening stage (see Question #4) you may elect to proceed directly to preemptive mitigation and consideration of remedies rather than conducting additional investigations (see Question #10).

If you elect to proceed with a multiple lines of evidence evaluation, as described below, you should prepare (and submit to DEQ for review and approval) an investigation and evaluation work plan, consistent with the requirements of Fact Sheet #8 *Site Investigation*, as applicable. The work plan should include the following elements (at a minimum):

a. The current VI SCM, including a summary of existing relevant data and data gaps.

b. The additional data that you plan to collect (including data quality objectives), number and locations of samples, field procedures, and laboratory analyses with reporting limits that meet applicable VRP screening and/or cleanup levels.

c. The lines of evidence that you propose for evaluating the potential for vapor intrusion at the site.

6. What lines of evidence should I use?

This Fact Sheet is not a "how to" manual; however, DEQ expects you to consider lines of evidence that are appropriate for site conditions in a manner consistent with other applicable VRP Fact Sheets (such as Fact Sheet #8 *Site Characterization* and Fact Sheet #29 *Sampling and Analysis Plans*) and good standard practice based upon relevant and current guidance (such as available from US EPA, ITRC, and other organizations). Useful, currently available references are listed in Question #13 of this Fact Sheet.

Several different lines of evidence that may be considered are listed below. This is not intended to be a complete list or limit the lines of evidence that you may consider. Further, the most pertinent and diagnostic lines of evidence vary from site to site, and not all lines of evidence are useful at any given site.

1. Nature and extent of subsurface contamination:

   Compounds, concentrations, and extent of contamination in groundwater, soil, soil gas, and sub-slab soil gas (as applicable), that are consistent with vapor transport processes are lines of evidence suggesting that vapor intrusion may be occurring. DEQ cautions that:

   a. Although deeper groundwater samples may be needed for a comprehensive understanding of the vertical extent of contamination (for evaluating the potential for vapor intrusion), groundwater samples should represent concentrations at the water table.

   b. Collection of soil gas samples should include adequate leak detection or prevention techniques (such as the use of helium shrouds or water dams, respectively). See the helium shroud example in Attachment B.

   c. Soil gas samples should be collected at varying depths to reflect the concentration profile with depth, including fixed gases when evaluating petroleum vapors.

   d. Sub-slab soil gas can also be impacted by indoor sources of contaminants, due to downward diffusion or advection of indoor air when building pressures are higher than sub-slab pressures.

2. Indoor air concentrations

   If compounds of concern are above groundwater and/or soil gas screening levels and buildings are present, it will likely be necessary to collect indoor air samples to confirm whether the vapor intrusion pathway is complete at concentrations above indoor air screening levels. Note that the elevations of sites in Wyoming will result in lower ambient air pressures (compared to sea level) that must be considered when shipping Summa canisters to lower elevation laboratories. (See ITRC, 2014 for a discussion of this issue or consult your laboratory.) If indoor air concentrations are above screening levels, it may be necessary to evaluate other lines of evidence to determine whether the exceedances are due to vapor intrusion and/or background sources. Commonly considered lines of evidence include, but are not limited to:

   a. Presence of the compounds in the subsurface above screening levels,

   b. Outdoor (ambient) air concentrations,

   c. Building survey for potential background sources,

d. Compound ratios in soil gas similar to those in indoor air (or compound ratios in groundwater, after multiplying the groundwater concentrations by the HLC),

e. Cross-slab pressure gradients (indicating upward or downward air flow at the time of indoor air testing),

f. The presence or lack of open cracks or other openings in the floor,

g. Typical ranges of background concentrations in similar buildings and settings (for context only, as actual background concentrations vary from building to building), and

h. The results of portable GC/MS screening of air near potential soil vapor entry points and/or potential indoor air sources.

3. Modeling

Modeling of the vapor intrusion pathway can provide a useful line of evidence, particularly for future buildings that cannot be tested. The most commonly used models are based on relatively simple, one-dimensional algorithms, such as the Johnson-Ettinger Model (JEM) and BioVapor (BV), which consider the primary pathway mechanisms partitioning from groundwater, diffusion in soils, advection into and dilution in buildings, and (in the case of BV) aerobic biodegradation of petroleum compounds in the vadose zone. US EPA (2017) and American Petroleum Institute (API, 2012) provide guidance for the appropriate use of the JEM and BV models, respectively.

DEQ will consider the results of modeling on the basis of whether it was conducted using representative site data (as applicable) and appropriate sensitivity analyses are considered to account for the potential influences of spatial and temporal variability. Even so, the results should be considered to have no more than one order of magnitude precision and should not be used on their own to rule out the potential for vapor intrusion.

4. Other lines of evidence
More advanced testing and/or evaluation techniques are available, and will be considered by DEQ on a case-specific basis, including (but not limited to):

a. Compound-specific stable isotope analysis, and

b. Building pressure cycling.

7. How do I address the potential for temporal variability?

The factors that influence indoor air concentrations due to vapor intrusion often vary over time. For example, concentrations in groundwater plumes migrating below a building can change over time, as can factors affecting the rate of diffusion of compounds in soil vapor (e.g., soil

temperature, soil moisture content). Building conditions, such as pressure differentials and air exchange rates, can change rapidly and affect indoor air concentrations by several factors or, in some cases, by an order of magnitude or more. Therefore, evaluations of the potential for vapor intrusion should also consider the impact of temporal variability on subsurface and indoor air concentrations.

With respect to subsurface conditions, DEQ typically requires at least seasonal (e.g., quarterly) sampling to characterize groundwater and soil gas concentrations over time. In some cases (e.g., when plumes are advancing or when remediation may affect the nature and extent of contamination), additional sampling may be required.

With respect to indoor air, if the results of initial testing indicate concentrations well above levels of concern, it may be more appropriate to proceed directly to mitigation and remediation. If the results of initial testing are more than an order of magnitude below levels of concern, and test conditions were representative of typical or worst-case conditions, then DEQ may consider the initial testing sufficient evidence that vapor intrusion is not a concern without additional indoor air testing if supported by all lines of evidence. If the results of initial testing are less than an order of magnitude below levels of concern, and/or tests were conducted under conditions less likely to cause vapor intrusion (e.g., during warm weather, positive building pressures, and/or high ventilation rates), then additional indoor air testing will be required under more typical and, ideally, worst-case conditions. In temperate climates like Wyoming, at least one test should be conducted during cold weather (i.e., heating) months. You should consult with your DEQ project manager to determine the appropriate number of testing events to reduce uncertainty due to temporal variation.

8. How do I address preferential pathways?

The term “preferential pathway” is often used to describe geologic or anthropogenic features that enhance the rate of soil vapor migration toward and into buildings, compared to the surrounding geology. Nearly all sites will have some preferential pathways that influence the direction and rate of soil vapor migration, and these should be identified during development of the VI SCM.

Most preferential pathways will not affect the applicability of the US EPA VISLs for groundwater and soil gas because these were developed based on the results of actual tests at hundreds of residential buildings across the US and using upper bound (i.e., conservative) values for observed attenuation between the subsurface and indoor air concentrations. Because the data from these sites would include typical preferential pathways (such as utilities and permeable, geologic deposits), the influence of these preferential pathways is included in the VISLs. Nevertheless, if a site is not screened out using the VISLs, the influence of any preferential pathway on the potential for vapor intrusion should be considered as a line of evidence.

On the other hand, certain less common preferential pathways can have a significant impact on indoor air concentrations. Such “atypical” pathways are generally open pipes or other conduits that directly connect the source of vapors with the building; essentially short-circuiting the vadose

zone pathway, where the rate of migration is typically diffusion-controlled. VISLs should not be used to screen out these sites, and more detailed evaluations should be conducted.

9. How do I assess the risk to human health due to vapor intrusion?

Under most circumstances, when the potential for vapor intrusion is considered to be high based on the multiple lines of evidence evaluation, you may elect to proceed directly to preemptive mitigation and remediation, rather than conducting additional investigations (see Question #10).

The multiple lines of evidence evaluation (described in Questions #5 – 8) relies on VISLs that incorporate default exposure factors for both residential and commercial exposure scenarios. The standard, default exposure factors underlying the VISLs are generally applicable to residential and commercial exposure scenarios for most buildings. In some cases, there are receptor or building-specific considerations (e.g., potential exposure frequency and duration, exposure factors, exposure pathways, or exposure routes) at a site that may affect the outcome of a vapor intrusion evaluation. If there are building-specific factors or exposure scenarios at your site that should be considered in the vapor intrusion evaluation, you may submit a building-specific risk assessment work plan (consistent with Fact Sheet #11 *Risk Assessment* and Fact Sheet #20 *Human Health Risk Assessment)* to DEQ for review and approval.

If the results of the risk assessment indicate an unacceptable risk to human health due to vapor intrusion, then you should proceed with an evaluation of remedial alternatives (see Question #10). In some cases, building mitigation as an interim measure may be appropriate to protect human health prior to (and in conjunction with) implementation of the final remedy, with DEQ approval.

10. How can vapor intrusion impacts be addressed?

In the long term, vapor intrusion is addressed by eliminating the source of the vapors using remedies selected according to Fact Sheet #21 *Remedy Selection*. In many cases, however, mitigation is needed to address the ongoing potential for vapor intrusion while remedy implementation is in progress. Mitigation measures include engineering or building controls and institutional controls, as applicable.

The most common building mitigation techniques for vapor intrusion are sub-slab depressurization (SSD) systems, often called “radon” systems because of their similarity to systems used to control entry of radon gas into buildings. Work plans for the installation of an SSD or any other type of building control system should be prepared by an experienced professional; consistent with current US EPA, ITRC, ASTM, or other applicable guidance and standards; and submitted to DEQ.

The work plans for mitigation should include appropriate operation, maintenance, and monitoring provisions to ensure protection of building occupants from vapor intrusion until the source of vapors has been remediated.

In some cases, an interim measure may be warranted prior to selection of a long term remedy, as approved by DEQ. This might include actions to reduce indoor air concentrations in the short term (e.g., sealing cracks, increasing ventilation, creating positive building pressures in commercial buildings, indoor air filtration) or possibly temporary relocation of building occupants. In these situations, DEQ will require submittal of an interim measure implementation work plan, and may specify that it include certain actions.

11. Where can I get more information on vapor intrusion?

The science of vapor intrusion is rapidly changing over time; therefore, you are encouraged to seek the most current and reliable information available. At the time this Fact Sheet was prepared, current state of the practice information on both general and petroleum vapor intrusion topics was available from US EPA and ITRC websites.

Many other sources of information are available, including American Society for Testing and Materials (ASTM), American Association of Radon Scientists and Technologists, Inc. (AARST), and API publications; various federal agencies, such as the Department of Defense Strategic Environmental Research and Development Program (SERDP) and Environmental Security Technology Certification Program (ESTCP); and other state agencies that have recently prepared detailed guidance documents. You should confer with your DEQ project manager when proposing to follow the procedures in any guidance document other than those specifically referenced in this Fact Sheet, and whenever the proposed procedures appear to deviate with the requirements of this Fact Sheet.

12. How can I get more information about the VRP?

To learn about VRP sites that may exist in your community, obtain copies of other VRP Fact Sheets and guidance documents, get answers to your questions, or volunteer for the program, contact DEQ at (307) 777-7752 or through the VRP website at: http://deq.wyoming.gov/shwd/voluntary-remediation-program/

The VRP website includes all of the Fact Sheets and other guidance documents for the VRP. This website is updated frequently and includes the latest information about DEQ's progress in developing guidance, policy, and other supporting documents for the VRP.

13. References

For additional information regarding vapor intrusion, please refer to the documents listed below.

API, 2012. *BioVapor User's Manual*, Version 2.1, American Petroleum Institute, November 2012.

ITRC, 2007. *Vapor Intrusion Pathway: A Practical Guideline*. Interstate Technology and Regulatory Council, Vapor Intrusion Team, January 2007.

ITRC, 2014. *Petroleum Vapor Intrusion*, Interstate Technology & Regulatory Council, Petroleum Vapor Intrusion Team, October 2014.

MDEQ, 2012. Typical Indoor Air Concentrations of Volatile Organic Compounds in Non-Smoking Montana Residences Not Impacted by Vapor Intrusion, A Montana Indoor Air Quality Investigation, Montana Department of Environmental Quality, August 2012.

US EPA, 1993. *Radon Reduction Techniques for Existing Detached Houses: Technical Guidance (Third Edition) for Active Soil Depressurization Systems*. U.S. Environmental Protection Agency Office Research and Development. EPA/625/R-93/011. Proceedings: Indoor Air 2002 919.

US EPA, 2008. *Indoor Air Vapor Intrusion Mitigation Approaches*, US EPA Engineering Issue, 2008.

US EPA, 2011a. *Background Indoor Air Concentrations of Volatile Organic Compounds in North American Residences (1990-2005): A Compilation of Statistics for Assessing Vapor Intrusion*, US EPA Office of Solid Waste and Emergency Response, EPA 530-R-10-001, June 2011.

US EPA, 2012. *Conceptual Model Scenarios for the Vapor Intrusion Pathway*, US EPA Office of Solid Waste and Emergency Response, EPA 530-R-10-003, February 2012.

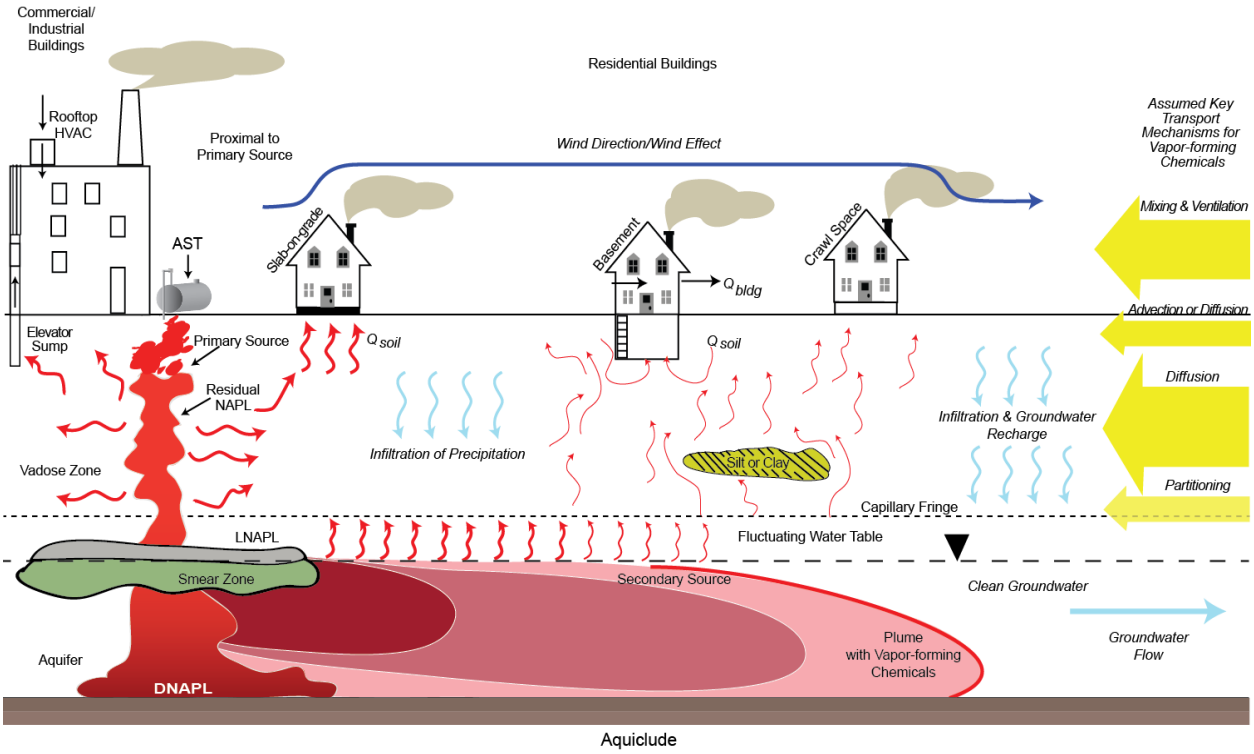
US EPA, 2015a. *OSWER Technical Guide for Assessing and Mitigating the Vapor Intrusion Pathway from Subsurface Vapor Sources to Indoor Air*, US EPA Office of Solid Waste and Emergency Response, Office of Solid Waste and Emergency Response (OSWER) Publication 9200.2-154, June 2015.

US EPA, 2015b. *Technical Guide for Addressing Petroleum Vapor Intrusion at Leaking Underground Storage Tank Sites*, US EPA Office of Underground Storage Tanks, Washington, D.C., EPA 510-R-15-001, June 2015.

US EPA, 2017. *Documentation for EPA's Implementation of the Johnson and Ettinger Model to Evaluate Site Specific Vapor Intrusion into Buildings*, Version 6.0, US EPA Office of Superfund Remediation and Technology Innovation, Washington, D.C., revised September 2017.

ATTACHMENT A

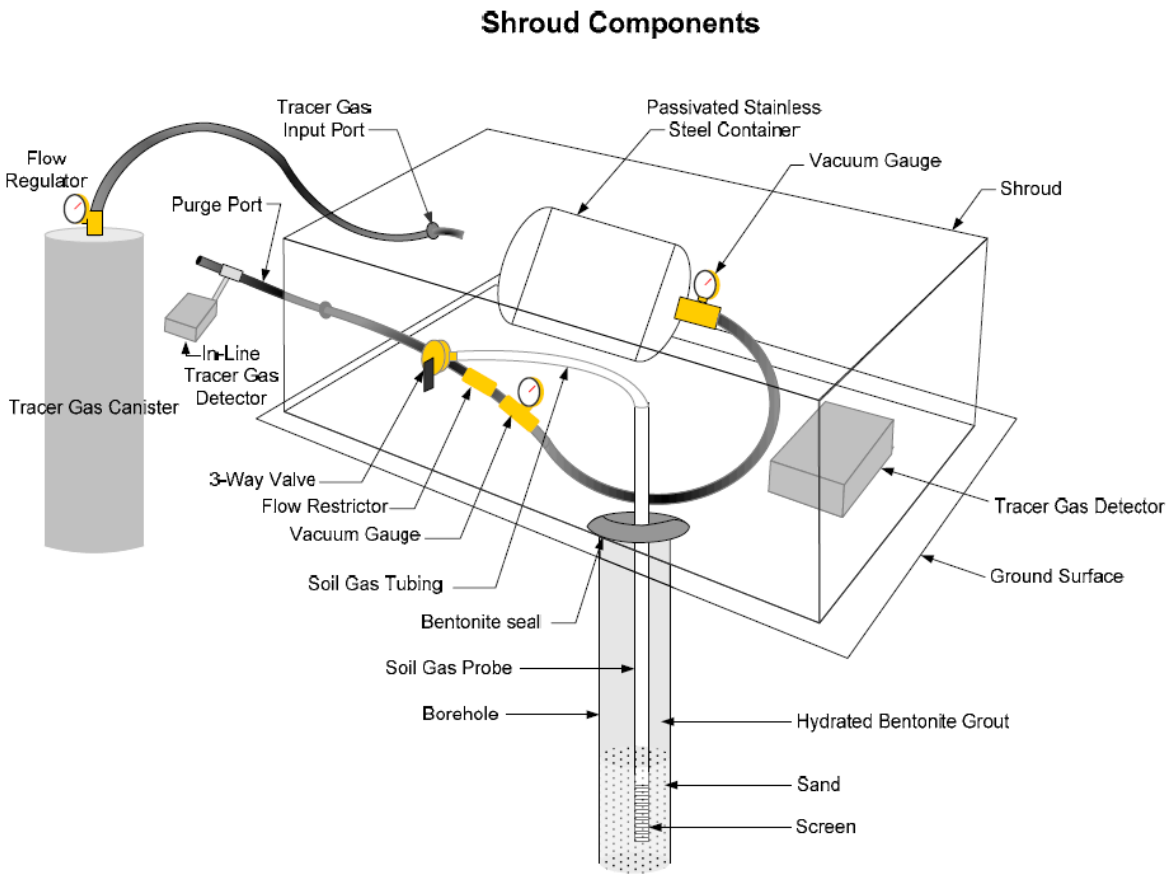
EXAMPLE VAPOR INTRUSION SITE CONCEPTUAL MODEL



Source: US EPA, *OSWER Technical Guide for Assessing and Mitigating the Vapor Intrusion Pathway from Subsurface Vapor Sources to Indoor Air*, Office of Solid Waste and Emergency Response, OSWER Publication 9200-2-154, Figure 2-1, June 2015.

ATTACHMENT B

EXAMPLE HELIUM SHROUD FOR SOIL GAS SAMPLING LEAK DETECTION



Source: California Environmental Protection Agency, Department of Toxic Substances Control, Los Angeles Water Quality Control Board, and San Francisco Regional Water Quality Control Board, *Active Soil Gas Investigations Advisory*, Appendix C, Quantitative Leak Testing Using a Tracer Gas, Figure C-1, April 2012.